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ScienceDirect
Procedia Engineering 91 (2014) 171 – 176
Procedia Engineering
www.elsevier.com/locate/procedia

XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP) (TFoCE 2014)

Spectral Analysis of the Structures due to Traffic

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Abstract

The paper deals with spectral analysis of two selected roadway bridges loaded with traffic seismicity due to road and railway traffic. The frequency parameters were obtained from computing model via *FEM* software. Spectral parameters comparison between theoretical and experimental results was realised. The traffic means effects on soil in frequency and amplitude domain was necessary for bridge spectral analysis.

Peer-review under responsibility of organizing committee of the XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP)

Keywords: spectral analysis; computing model; random vibration; stochastic; natural frequencies; natural modes;

1. Introduction

The high increase of the traffic intensity starts to be more of a problem. All buildings and most bridges are close to roads, railways and they are influenced by paraseismic load due to traffic means. During the lifetime of the structure, a moving load causes fatigue and cracks to the bridges and all additional dynamic load may decrease serviceability of the bridge. One of the most useful methods of bridge assessment is theoretical and experimental evaluation of spectral characteristics of all subsystems (traffic mean, soil, structure).

Nomenclature

$G_{ii}(f)$	auto power spectral density
$G_{ik}(f)$	cross power spectral density
$\gamma_{ik}(f)$	coherence function
$H_{ik}(f)$	gain factor
$R_{ik}(\tau)$	cross correlation function
x_{ef}	effective value

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Peer-review under responsibility of organizing committee of the XXIII R-S-P seminar, Theoretical Foundation of Civil Engineering (23RSP)
doi:10.1016/j.proeng.2014.12.041

2. Theoretical spectral analysis

The stochastic vibration assumption can only be analyzed the paraseismic effect. In the random vibration process, the followed evaluation areas are known:

- the time domain (signal in time),
- correlation (correlation between two random processes),

effective value

$$\sigma_x = RMS = x_{ef} = \sqrt{\frac{1}{T}\int_0^T x(t)^2\, dt}\,. \tag{1}$$

autocorrelation function

$$R_{xx}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_0^T x(t)x(t+\tau)dt\,. \tag{2}$$

- frequency domain (harmonic analysis),
- spectral evaluation (transformation time processes to frequency domain),

power spectral density

$$G_{xx}(f) = 2\int_{-\infty}^{\infty} R_{xx}(\tau)e^{-i2\pi f\tau}\, dt \tag{3}$$

coherency function

$$\gamma_{xy}(f)^2 = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f)G_{yy}(f)} \le 1. \tag{4}$$

gain factor, transfer function

$$H(if) = \frac{G_{xy}(f)}{G_{xx}(f)}. \tag{5}$$

- probabilistic area (statistic parameters),
- informatics (effective – determined signal in noise).

For the base frequency parameters of the traffic means (vehicle, train) very simplified computing models were created. The stiffness constant method was used for calculation on two variants of computing model:

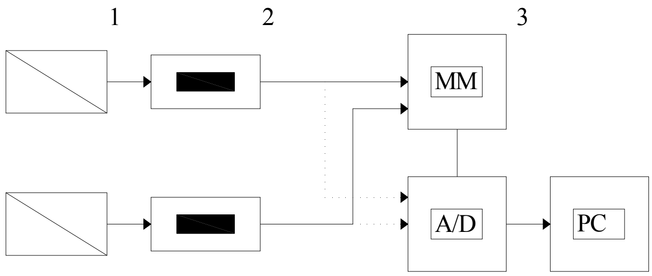
- quarter planar model (one axle of vehicle)
- space model (according most characteristic masses)

The parameters for computing model creation were considered as standard average values from literature [1] for heavy and light vehicle.

The base dynamic parameters of bridge structures are obtained with help of a computing system *IDA NEXIS* using final element method. This system enables us to create framed and shell dynamic model according bridge geometry, mass distribution and border condition.

3. Stectral analysis – case studies

A real dynamic response of the structure can be received via relevant measurement equipment. All presented measurements were performed by Department of Structural Mechanics (DSM) Faculty of Civil Engineering (FCE) University of Žilina (ŽU) based on the evaluation of software lines DSM. The Off-Line method was used and its scheme is shown in Fig. 1.



1 – accelerometers
(B&K 8306,Robotron KB12-RFT)
2 – integration amplyfiers
(B&K 2635, Robotron 00042)
3 – recording source (B&K 7005)
laptop or PC with software (DAS 16, DISYS,NI LabView) with A/D converter

Fig. 1. Used Off-Line method scheme.

Dynamic response of real environment (half-space) and bridge structures loaded by random excitation was measured using 12 accelerometers sets with a frequency range of 1 ÷ 4000 Hz. (*Brüel-Kjaer*). The accelerometers were situated on ground and on the bridges. The accelerometers measured response in the vertical direction. Dynamic response in the observed points was measured in the form of vibration acceleration (m/s2), in three orthogonal directions *x, y, z*. The measurements were performed using the "off - line" method. The recorded signals were simultaneously being saved in two PCs - AMILO and PC FS (National Instrument Compact DAQ software). Evaluation of the measured data was also carried out in laboratory conditions of DSM, FCE, ŽU based on the evaluation of software lines DSM. The measuring unit consisted of:

- piezoelectric accelerometers BK 8306 (Bruel - Kjaer) - 5pcs,
- integration amplifier BK-2693-014 (Brüel-Kjaer),
- AD converters NI Compact DAQ (NI - National Instrument), Notebooks.

Mechanical movement in the measuring points has been transformed by measuring line of accelerometers from an electrical signal after amplification and integration to the vibration acceleration - *a (t)* and vibration velocity - *v (t)*. It was conducted by means of shielded cables leading to the measuring center near the object. Notebooks are working NI Compact DAQ AD converters. The analog signal was recorded and saved using NI Lab View software with the sampled frequency f_s = 500 Hz (the required criteria for sampling signals is $\Delta t < 1/2\, f_{max}$).

3.1. Spectral characteristics – Bridge Over the Kysuca Road – Žilina

The prestressed road *Bridge over the Kysuca road* was used as the representative new structure loaded due to road traffic technical seismicity effects. Technical parameters are shown in [2]. The measurement sensors position simple scheme and the view of the bridge is presented in Fig. 2.

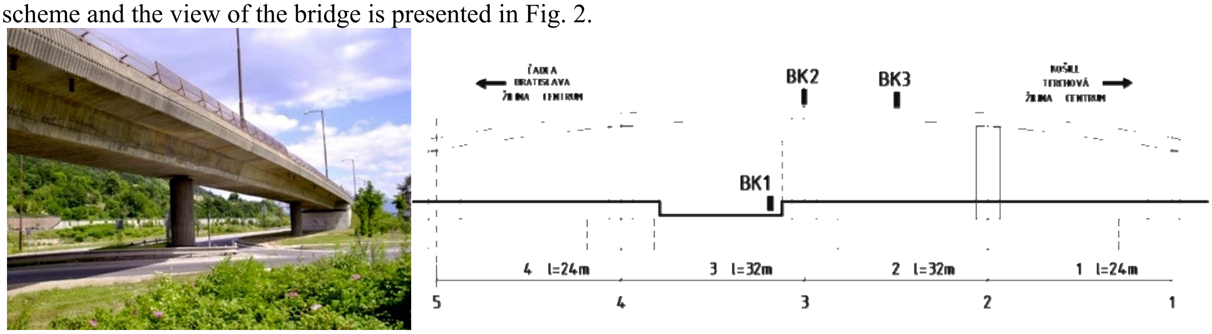


Fig. 2. View of *Bridge Over the Kysuca Road – Žilina*, sensor position scheme.

The measurement and evaluation of vibration due to paraseismic from roadway traffic were performed on a real bridge structure. The FEM model and numerical results were also calculated and compared with the experiment, (Fig. 3).

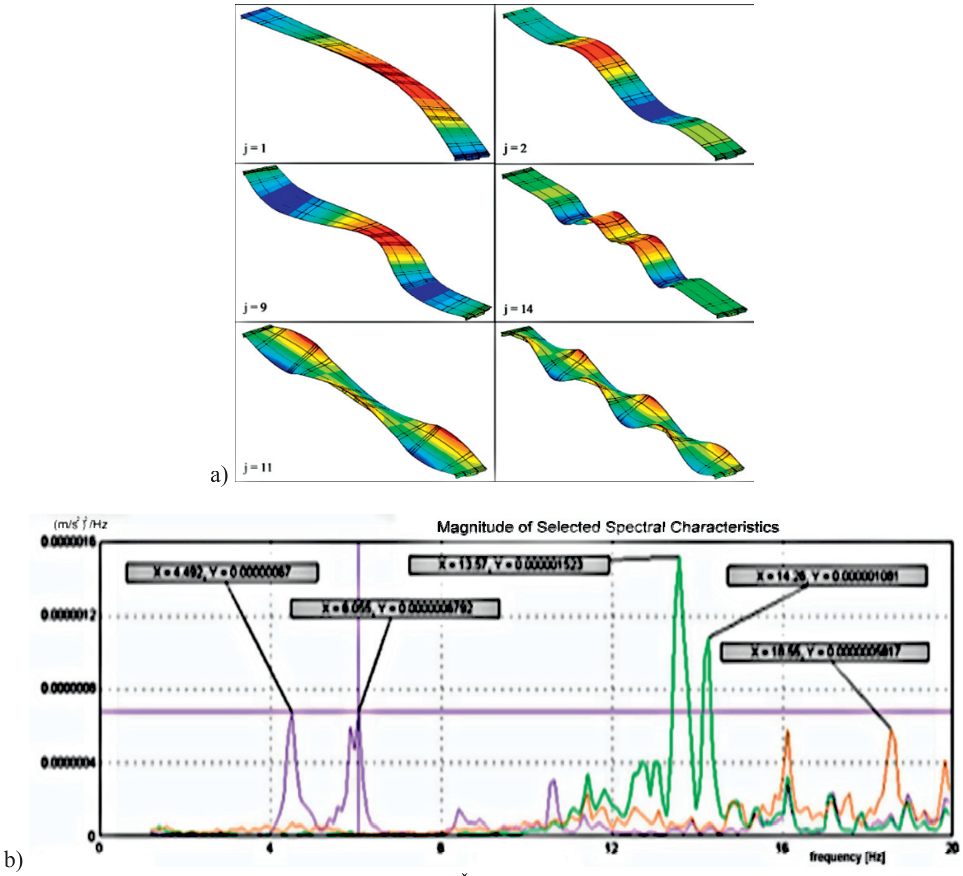


Fig. 3.(a), (b) Bridge over the Kysuca road – Žilina case study spectral characteristics examples.

3.2. Spectral characteristics – Bridge – D201 – 00 – CI / 11 Žilina – scaffold bridge

The prestressed road *Bridge – D201 – 00 – CI / 11 Žilina* was used as the representative new structure loaded due to railway traffic technical seismicity effects. Technical parameters are in [2]. The measurement sensors position simple scheme and the view of the bridge is presented in Fig. 4.

Fig. 4. View of *Bridge – D201 – 00 – CI / 11 Žilina*.

On the next real bridge structure the measurement and evaluation of vibration due to paraseismic from railway traffic were performed.

Also *FE* model and numerical results were calculated and compared with experiment for this bridge (Fig. 5).

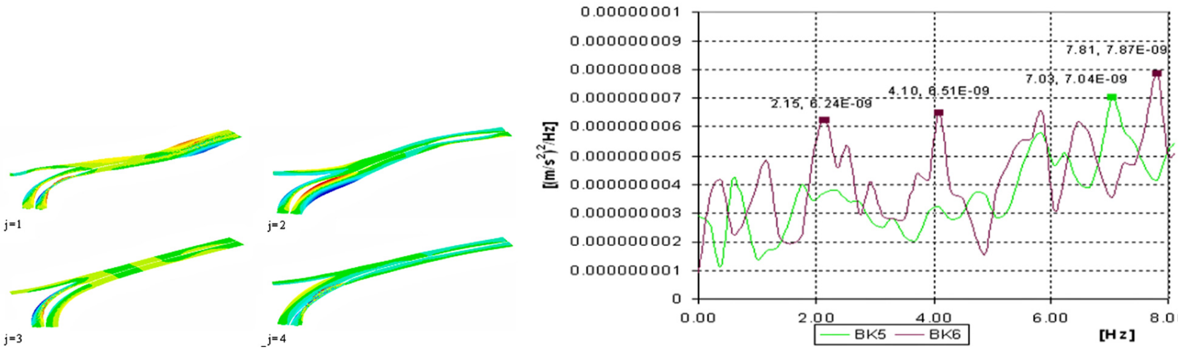


Fig. 5. D201 – 00 – CI / 11 Žilina – scaffold bridge case study spectral characteristics examples from traffic load.

3.3. Vibration of the soil due to traffic means

The measurement of vibration due to traffic means was performed close to inspected bridges. The intensity decreasing in dependence on the distance from the vibration source was processed [3]. The gain factor functions and the other spectral functions were also analysed in two locations: Near the MŠK Žilina football stadium (roadway traffic) and Teplička over the Váh River (railway traffic). The examples of results are shown on Fig. 6 and Fig. 7.

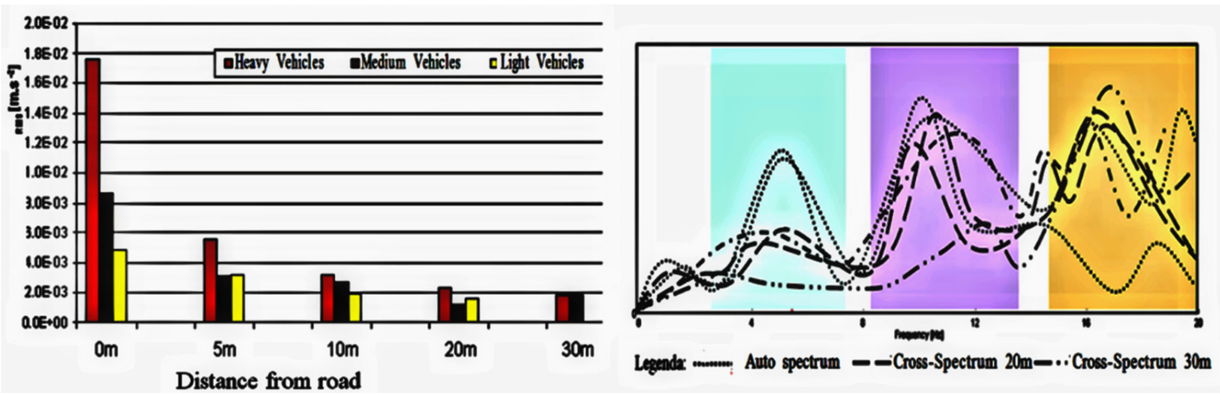


Fig. 6. *MŠK Žilina* football stadium locality experimental results examples.

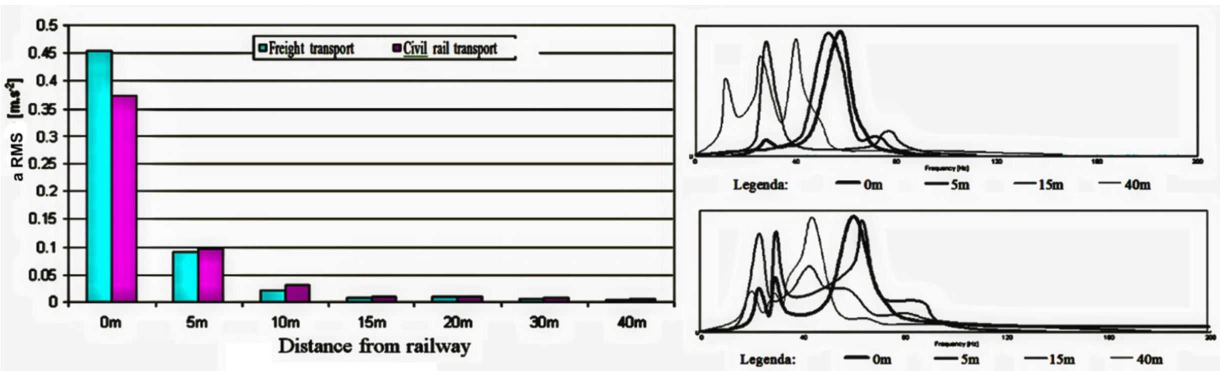


Fig. 7. Teplička over the Váh River locality experimental results examples.

4. Conclusions

The main aim of theoretical and experimental spectral analysis was to identify the frequency characteristics of selected bridge structures. These characteristics were analysed for bridge dynamic load and response due to paraseismic effect involved by road and railway traffic. For both bridges, the dominant frequency bands were identified and correspond with natural frequency peaks in numerical model simulation. For all these case studies, the frequency transfer (via spectral characteristics) and the vibration level decreases depending on the distance from the vibration source were observed. These case studies show some dominant frequency bands for railway and for road traffic [4, 5].

The case studies results for the transmission of the soil environment vibration and bridge structure vibration obtain the following conclusions:

- The intensity of vibration from the source of vibration through the rock and soil environment to the basis of bridge supports decreases exponentially with distance, as well as from the influence of road and rail traffic.
- To identify the dominant vibration associated with the vehicle, the precise specification of the vehicle dynamic parameters must be known. The simple estimation of vehicle parameters can be identified with measurements. The rail can expect two kinds of dominant frequency domain associated with natural vibration of the track grid structure and associated with the vibration of railway vehicles. The case study identified the dominant frequency: 55-65 Hz (track grid with vehicle mass) and 22-36 Hz (above rail vehicle vibration modes).
- Transfer functions and basic mechanical properties of soil in the study area were identified based on the ISM (Impulse Seismic Method). The inter-frequency transmission is mostly realized in the frequency range 35-45 Hz.

Acknowledgement

This paper was created with the support of the OP Education for the project „Education quality support and research for the transport sector as the engine of the economy" (ITMS: 26110230076), which is co-financed by the European Social Fund.

Modern education for the knowledge society / Project co-financed from EU sources.

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